Query decomposition and data localization

Dario Della Monica

These slides are a modified version of the slides provided with the book

Özsu and Valduriez, *Principles of Distributed Database Systems* (3rd Ed.), 2011

The original version of the slides is available at: extras.springer.com

Outline (distributed DB)

- Introduction (Ch. 1) *

- Distributed Database Design (Ch. 3) *

- Distributed Query Processing (Ch. 6-8) *
  - → Overview (Ch. 6) *
  - → **Query decomposition and data localization (Ch. 7)** *
  - → Distributed query optimization (Ch. 8) *

- Distributed Transaction Management (Ch. 10-12) *

* Özsu and Valduriez, *Principles of Distributed Database Systems* (3rd Ed.), 2011

Outline (today)

- Query decomposition and **data localization** (Ch. 7) *

  → The problem of distributed data localization

  → A naïve algorithm

  → Optimization steps (reductions)

    ✦ PHF (selection, join)

    ✦ VF (projection)

    ✦ DHF (join)

    ✦ Hybrid Fragmentation (selection/join + projection)

Data Localization

Input: Relational algebra expression on global, distributed relations (distributed query)

Output: Relational algebra expression on fragments (localized query)

- Localization uses global information about distribution of fragments (no use of quantitative information, e.g., catalog statistics)

- Recall that fragmentation is obtained by several application of rules expressed by relational algebra …

  → primary horizontal fragmentation: selection σ

  → derived horizontal fragmentation: semijoin $\ltimes$

  → vertical fragmentation: projection Π

- … and that reconstruction (reverse fragmentation) rules are also expressed in relational algebra

  → horizontal fragmentation: union $\cup$

  → vertical fragmentation: join $\bowtie$

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A naïve algorithm to localize distribute queries

- Localization program: relational algebra expression that reconstructs a global relation from its fragments, by reverting the rules employed for fragmentation

- A localized query is obtained from distributed, global query by replacing leaves (global relations) with (the tree of) its corresponding localization program

  → Leaves of localized queries are fragments

- This approach to obtain a localized query from a distributed one is inefficient and the result can be improved through several optimizations

  → During data localization there is a **first optimization phase**

    ✦ we call it **reduction**

    ✦ different from the **proper optimization phase** (finding the "best" strategy for executing the query)

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Example

$$EMP \bowtie ASG$$

Example

Assume

$$EMP \bowtie ASG$$

- EMP is fragmented as follows:

  → $EMP_1 = \sigma_{ENO \leq "E3"}(EMP)$

  → $EMP_2 = \sigma_{"E3" < ENO \leq "E6"}(EMP)$

  → $EMP_3 = \sigma_{ENO \geq "E6"}(EMP)$

- ASG is fragmented as follows:

  → $ASG_1 = \sigma_{ENO \leq "E3"}(ASG)$

  → $ASG_2 = \sigma_{ENO > "E3"}(ASG)$

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Example

Assume

EMP ⋈ ASG

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- ASG is fragmented as follows:

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Replace EMP by $(EMP_1 \cup EMP_2 \cup EMP_3)$
and ASG by $(ASG_1 \cup ASG_2)$ in any query

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Example

Assume

- EMP is fragmented as follows:

  → $EMP_1 = \sigma_{ENO \leq "E3"}(EMP)$

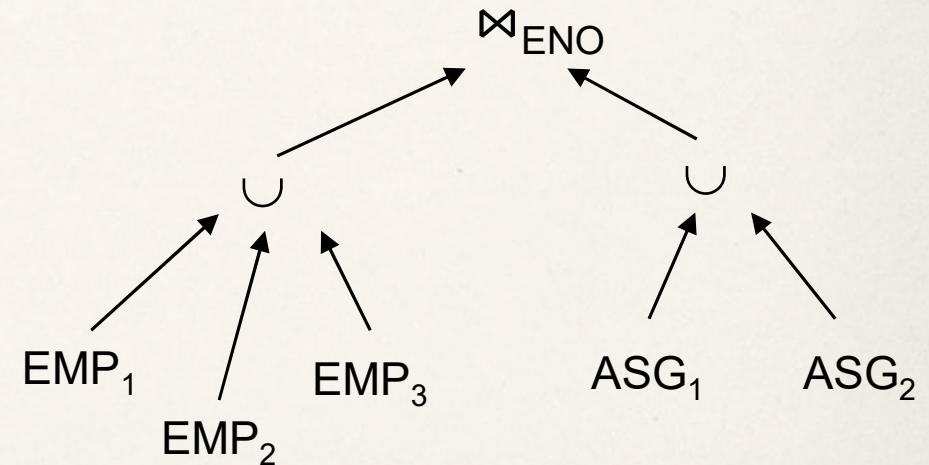 → $EMP_2 = \sigma_{"E3" < ENO \leq "E6"}(EMP)$

  → $EMP_3 = \sigma_{ENO \geq "E6"}(EMP)$

- ASG is fragmented as follows:

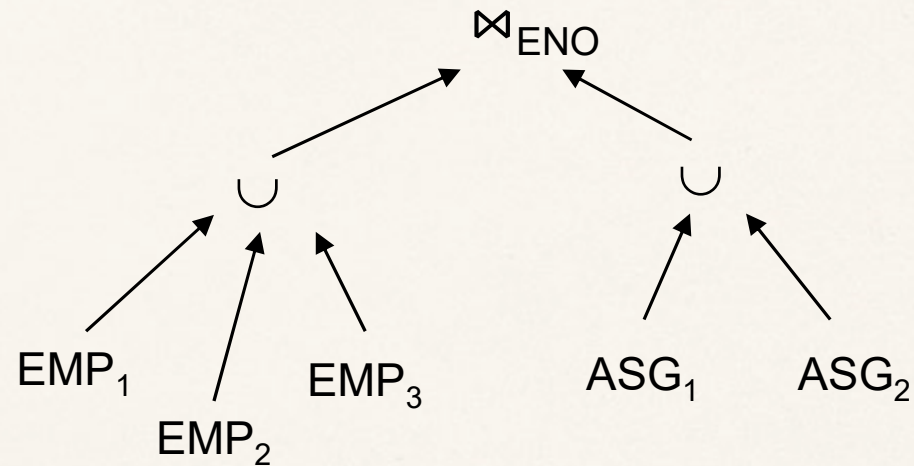 → $ASG_1 = \sigma_{ENO \leq "E3"}(ASG)$

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Replace EMP by $(EMP_1 \cup EMP_2 \cup EMP_3)$
and ASG by $(ASG_1 \cup ASG_2)$ in any query

$$EMP \bowtie ASG$$
$$=$$
$$(EMP_1 \cup EMP_2 \cup EMP_3) \bowtie (ASG_1 \cup ASG_2)$$

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Example

Assume

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  → $EMP_1 = \sigma_{ENO \leq "E3"}(EMP)$

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Replace EMP by $(EMP_1 \cup EMP_2 \cup EMP_3)$ and ASG by $(ASG_1 \cup ASG_2)$ in any query

$$EMP \bowtie ASG$$
$$=$$
$$(EMP_1 \cup EMP_2 \cup EMP_3) \bowtie (ASG_1 \cup ASG_2)$$

Provides Parallellism

$$(EMP_1 \cup EMP_2 \cup EMP_3) \bowtie (ASG_1 \cup ASG_2)$$

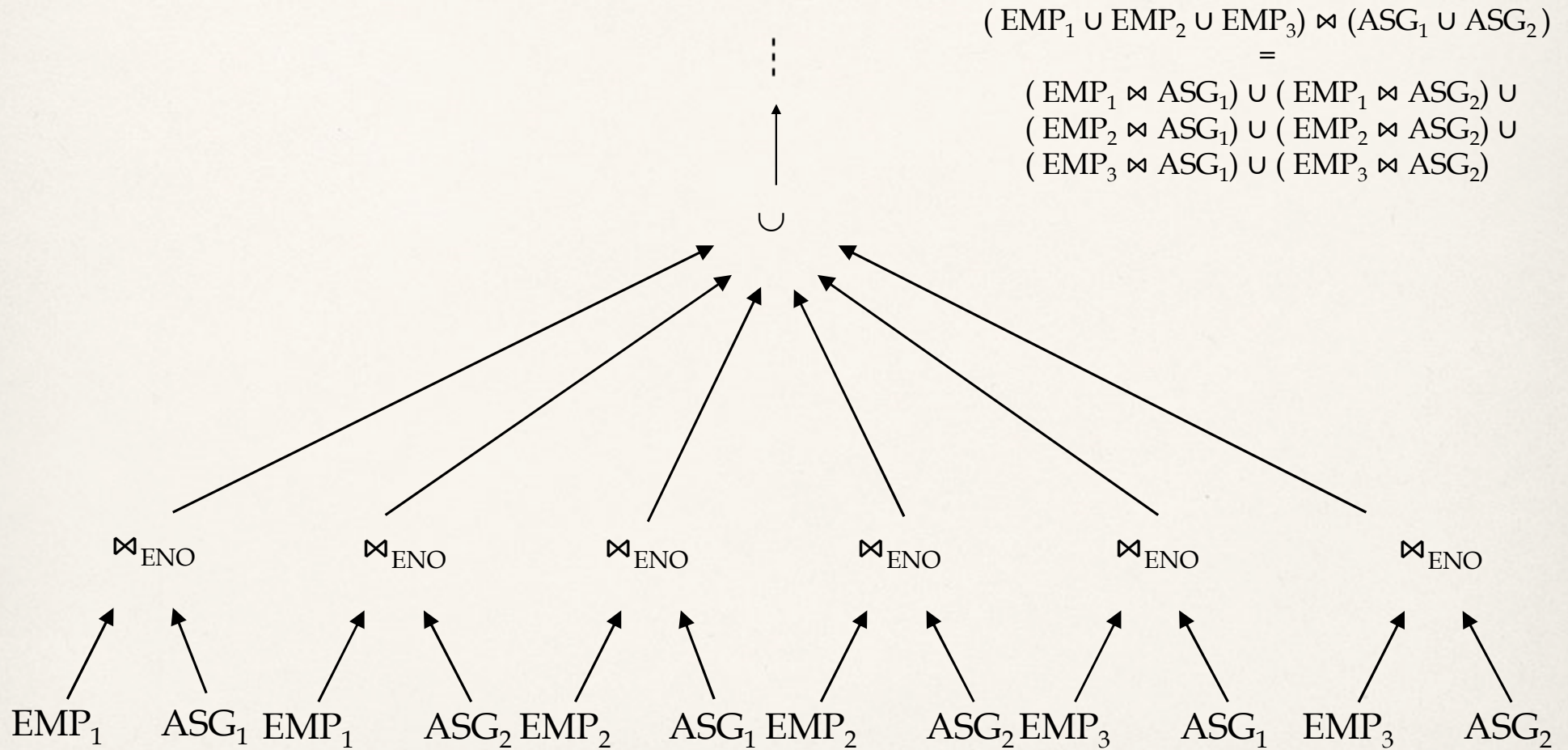© M. T. Özsu & P. Valduriez

Provides Parallellism

$$(\text{EMP}_1 \cup \text{EMP}_2 \cup \text{EMP}_3) \bowtie (\text{ASG}_1 \cup \text{ASG}_2)$$
$$=$$
$$(\text{EMP}_1 \bowtie \text{ASG}_1) \cup (\text{EMP}_1 \bowtie \text{ASG}_2) \cup$$
$$(\text{EMP}_2 \bowtie \text{ASG}_1) \cup (\text{EMP}_2 \bowtie \text{ASG}_2) \cup$$
$$(\text{EMP}_3 \bowtie \text{ASG}_1) \cup (\text{EMP}_3 \bowtie \text{ASG}_2)$$

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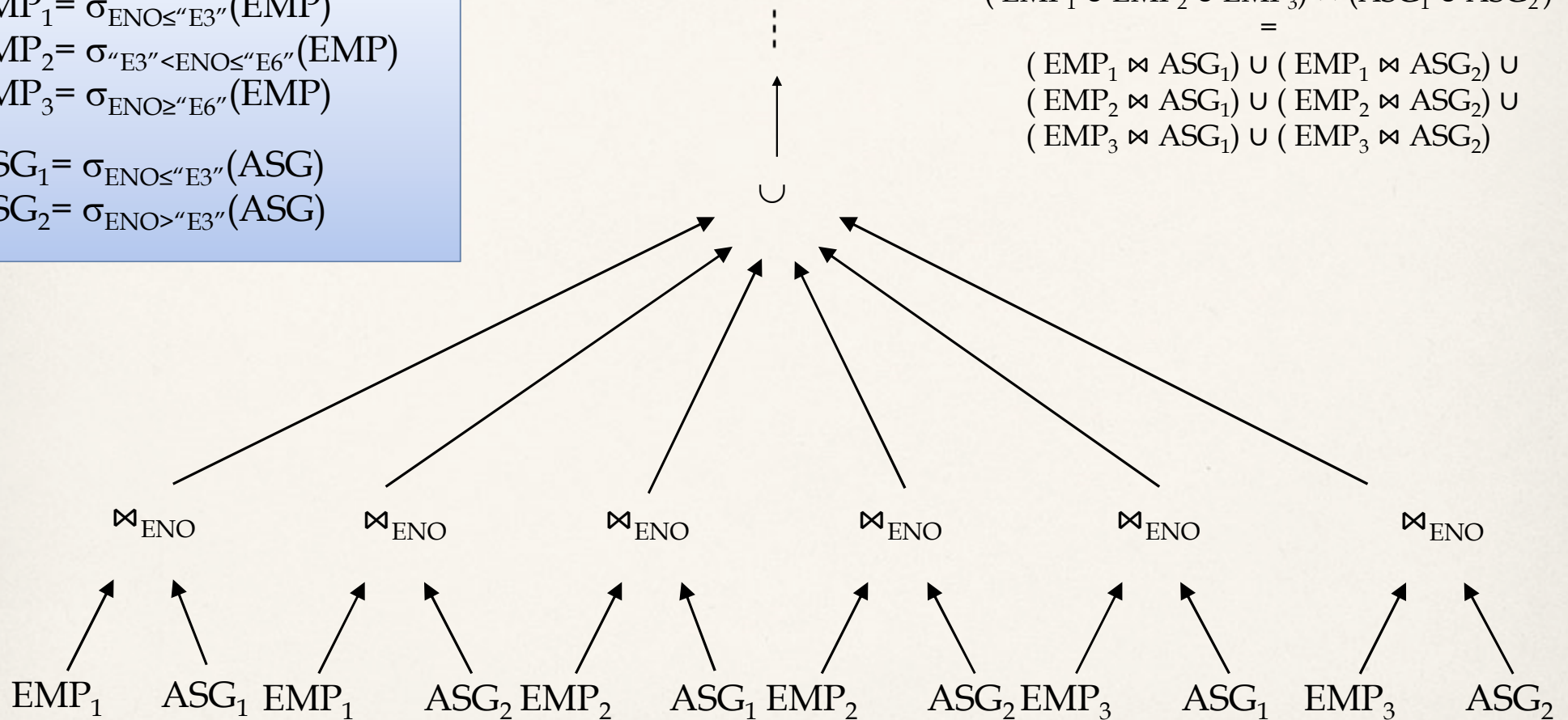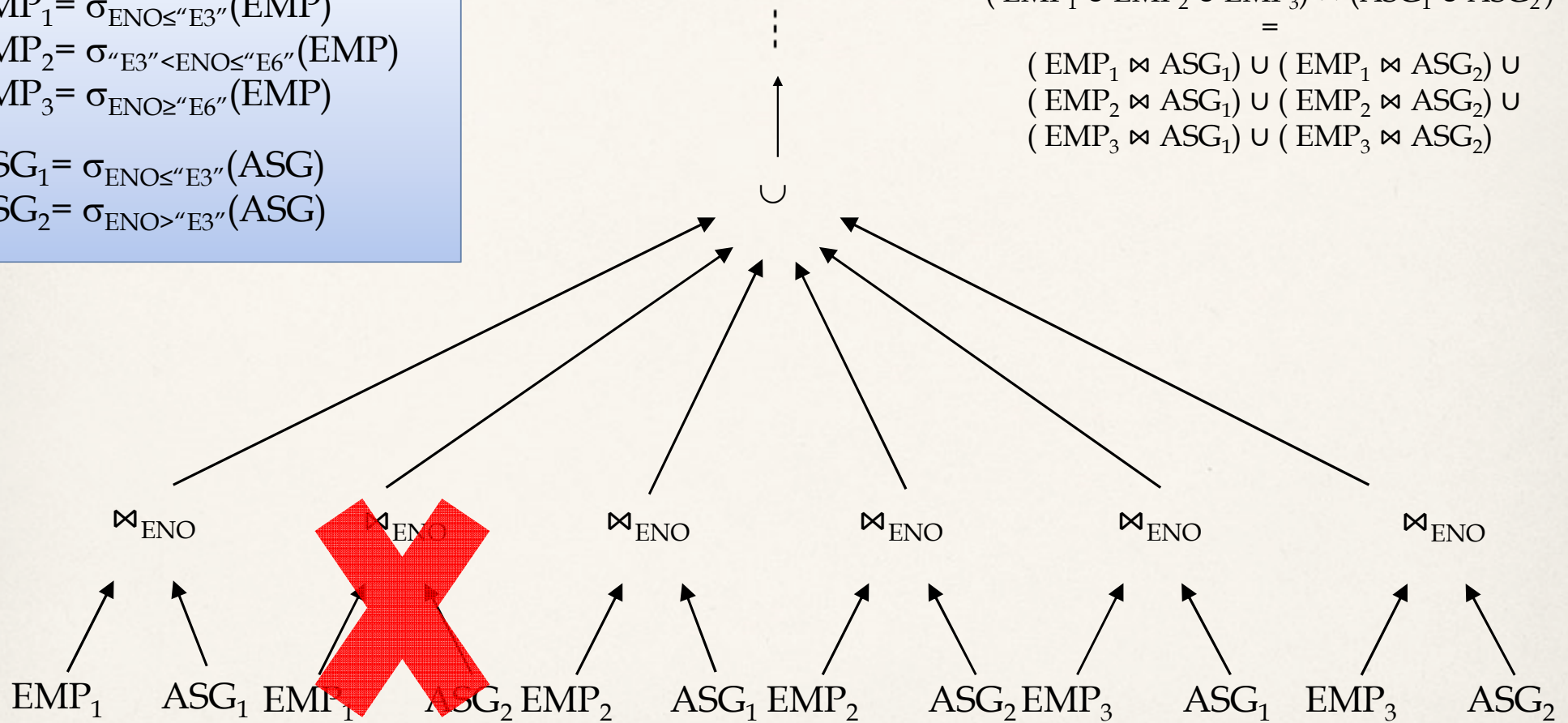© M. T. Özsu & P. Valduriez

Provides Parallellism

$EMP_1 = \sigma_{ENO \leq "E3"}(EMP)$
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$EMP_3 = \sigma_{ENO \geq "E6"}(EMP)$

$ASG_1 = \sigma_{ENO \leq "E3"}(ASG)$
$ASG_2 = \sigma_{ENO > "E3"}(ASG)$

$(EMP_1 \cup EMP_2 \cup EMP_3) \bowtie (ASG_1 \cup ASG_2)$
$$=$$
$(EMP_1 \bowtie ASG_1) \cup (EMP_1 \bowtie ASG_2) \cup$
$(EMP_2 \bowtie ASG_1) \cup (EMP_2 \bowtie ASG_2) \cup$
$(EMP_3 \bowtie ASG_1) \cup (EMP_3 \bowtie ASG_2)$

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Provides Parallellism

$EMP_1 = \sigma_{ENO \leq "E3"}(EMP)$

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$ASG_1 = \sigma_{ENO \leq "E3"}(ASG)$
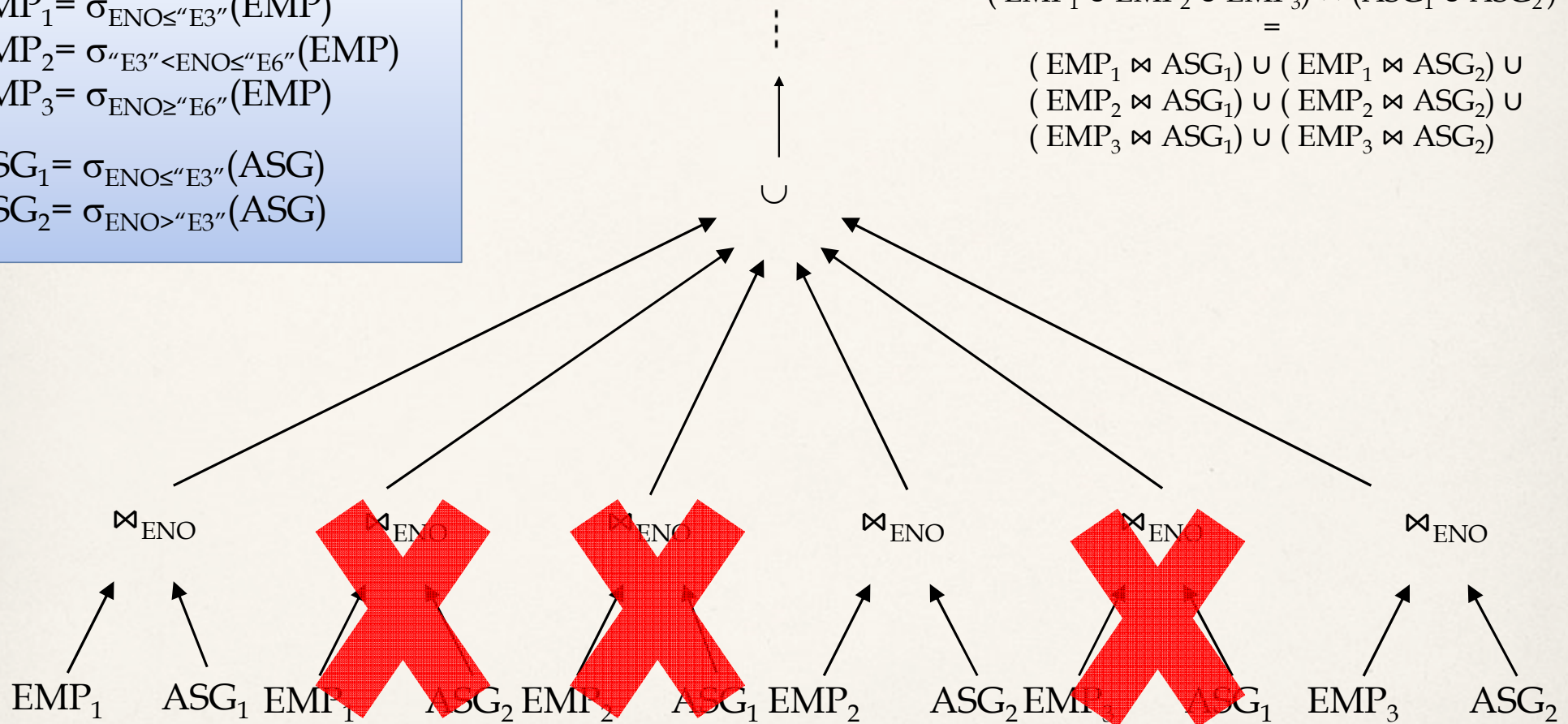
$ASG_2 = \sigma_{ENO > "E3"}(ASG)$

$$(EMP_1 \cup EMP_2 \cup EMP_3) \bowtie (ASG_1 \cup ASG_2)$$
$$=$$
$$(EMP_1 \bowtie ASG_1) \cup (EMP_1 \bowtie ASG_2) \cup$$
$$(EMP_2 \bowtie ASG_1) \cup (EMP_2 \bowtie ASG_2) \cup$$
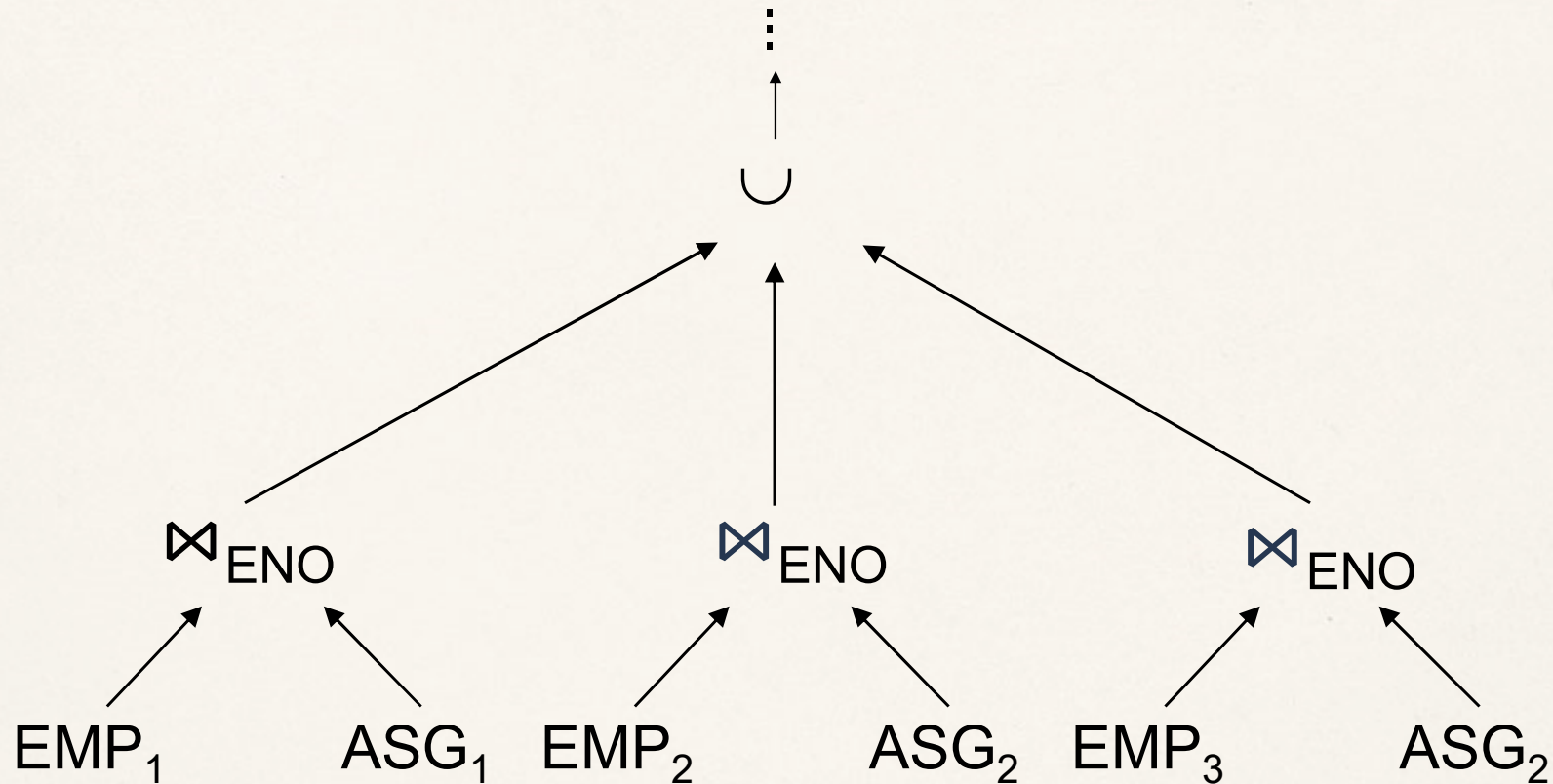$$(EMP_3 \bowtie ASG_1) \cup (EMP_3 \bowtie ASG_2)$$

Provides Parallellism

$EMP_1 = \sigma_{ENO \leq "E3"}(EMP)$
$EMP_2 = \sigma_{"E3" < ENO \leq "E6"}(EMP)$
$EMP_3 = \sigma_{ENO \geq "E6"}(EMP)$

$ASG_1 = \sigma_{ENO \leq "E3"}(ASG)$
$ASG_2 = \sigma_{ENO > "E3"}(ASG)$

$$(EMP_1 \cup EMP_2 \cup EMP_3) \bowtie (ASG_1 \cup ASG_2)$$
$$=$$
$$(EMP_1 \bowtie ASG_1) \cup (EMP_1 \bowtie ASG_2) \cup$$
$$(EMP_2 \bowtie ASG_1) \cup (EMP_2 \bowtie ASG_2) \cup$$
$$(EMP_3 \bowtie ASG_1) \cup (EMP_3 \bowtie ASG_2)$$

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Eliminates Unnecessary Work

Identify (pairs of) fragments that can be ignored because they produce empty relations (e.g., when a selection or a join is applied to them)

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Reduction for PHF – Selection

- Reduction of a selection over a relation fragmented with PHF: ignore a fragment if selection predicate and fragment predicate are contradictory

  → Consider $\sigma_p(R)$

  → Horizontal fragmentation on R: $F_R = \{R_1, R_2, \ldots, R_w\}$, where $R_j = \sigma_{p_j}(R)$

  → $\sigma_p(R_j) = \varnothing$ if $\forall x$ in R: $\neg(p(x) \wedge p_j(x))$ i.e., p and p_j are contradictory

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Reduction for PHF – Selection (Example)

- Reduction of a selection over a relation fragmented with PHF: ignore a fragment if selection predicate and fragment predicate are contradictory

→ Example

```
SELECT    *
FROM      EMP
WHERE     ENO="E5"
```
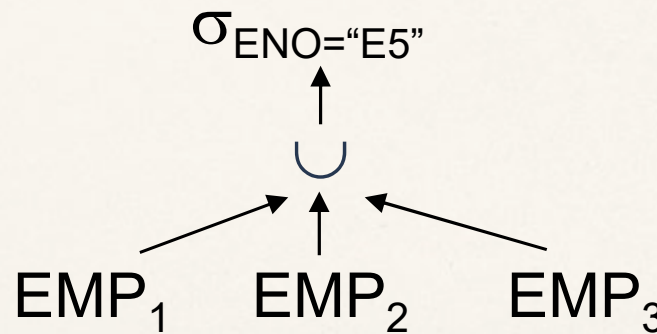
$EMP_1 = \sigma_{ENO\leq"E3"}(EMP)$
$EMP_2 = \sigma_{"E3"<ENO\leq"E6"}(EMP)$
$EMP_3 = \sigma_{ENO\geq"E6"}(EMP)$

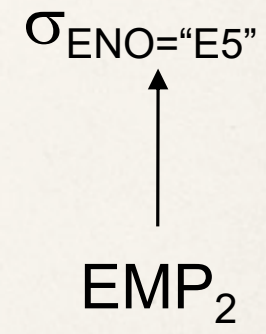$ASG_1 = \sigma_{ENO\leq"E3"}(ASG)$
$ASG_2 = \sigma_{ENO>"E3"}(ASG)$

$\sigma_{ENO="E5"}$ $\sigma_{ENO="E5"}$ $\sigma_{ENO="E5"}$

EMP $\cup$ EMP_2

EMP_1 EMP_2 EMP_3

distributed query   **localized query**   **reduced local query**

Reduction for PHF – Join

- Reduction of a join over relations fragmented with PHF: ignore the join of 2 fragments if their fragment predicates are contradictory over the join attributes

  → Possible if fragmentation is done on join attribute

  → Distribute join over union

$$R \bowtie S \Leftrightarrow (R_1 \cup R_2) \bowtie (S_1 \cup S_2)$$
$$\Leftrightarrow (R_1 \bowtie S_1) \cup (R_1 \bowtie S_2) \cup (R_2 \bowtie S_1) \cup (R_2 \bowtie S_2)$$
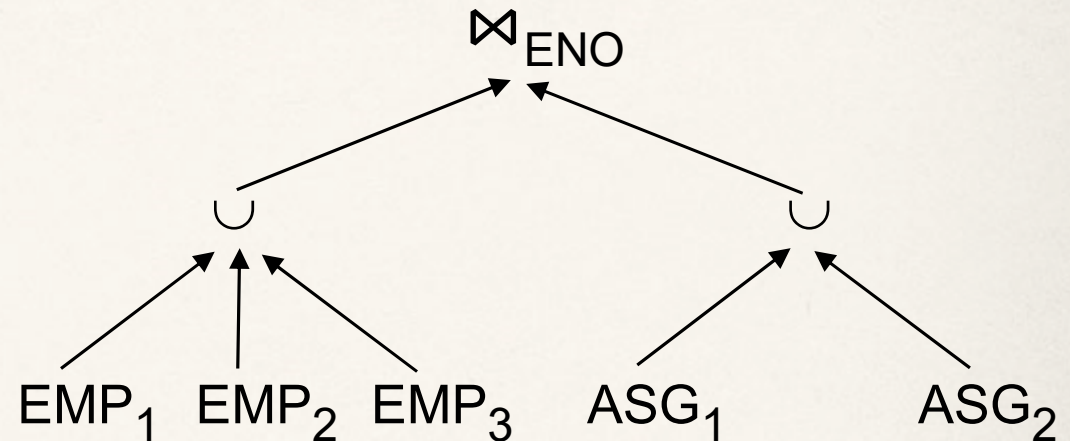
  → Then, join between 2 fragments can be simplified in some cases

  ✦ Given $R_i = \sigma_{p_i}(R)$ and $S_j = \sigma_{p_j}(S)$ [p_i and p_j defined over join attributes]

$$R_i \bowtie S_j = \varnothing \text{ if } \forall x \text{ in } R \bowtie S : \neg(p_i(x) \wedge p_j(x)) \quad \textit{[there is a mistake in the textbook]}$$

i.e., p_i and p_j are contradictory
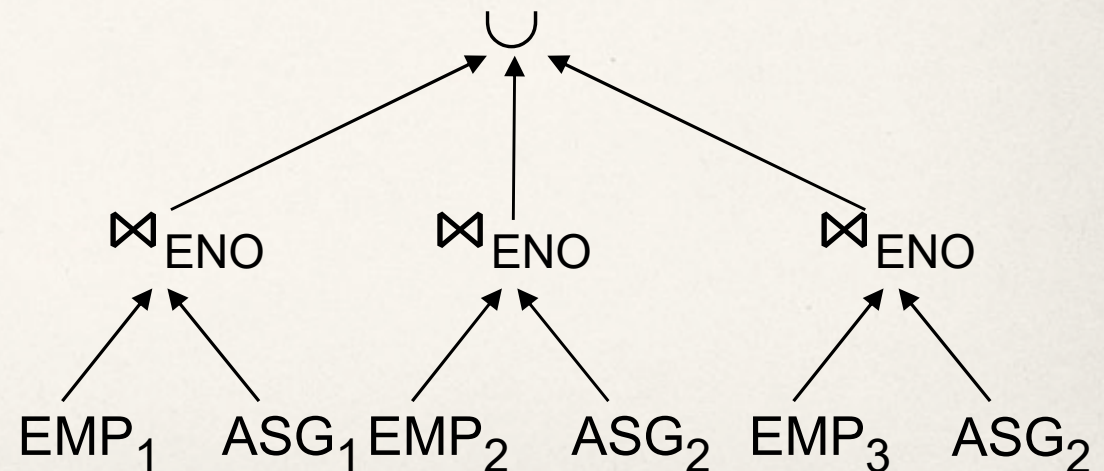
Reduction for PHF – Join (Example)

$EMP_1 = \sigma_{ENO \leq "E3"}(EMP)$
$EMP_2 = \sigma_{"E3" < ENO \leq "E6"}(EMP)$
$EMP_3 = \sigma_{ENO \geq "E6"}(EMP)$

$ASG_1 = \sigma_{ENO \leq "E3"}(ASG)$
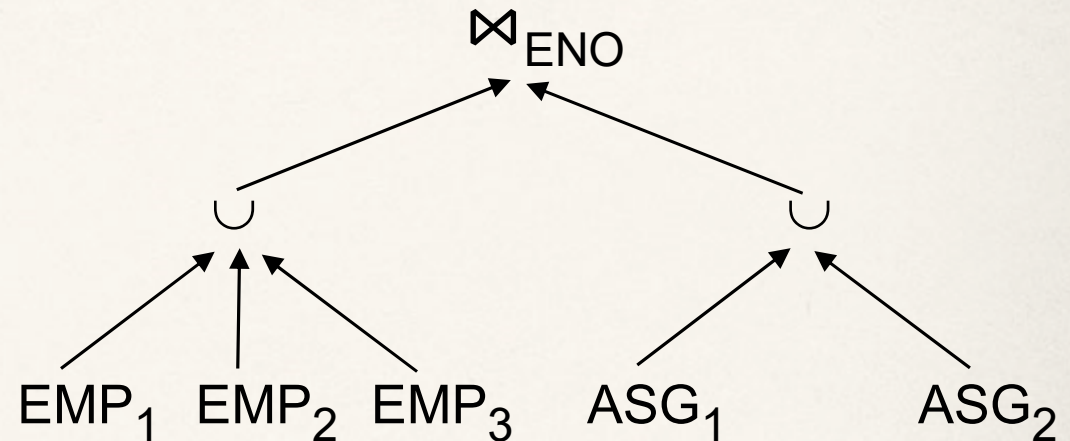$ASG_2 = \sigma_{ENO > "E3"}(ASG)$

- Consider the query

```
SELECT   *
FROM     EMP,ASG
WHERE    EMP.ENO=ASG.ENO
```

- Distribute join over unions
- Apply the reduction rule

Reduction for PHF – Join (Example)

$EMP_1 = \sigma_{ENO \leq "E3"}(EMP)$
$EMP_2 = \sigma_{"E3" < ENO \leq "E6"}(EMP)$
$EMP_3 = \sigma_{ENO \geq "E6"}(EMP)$

$ASG_1 = \sigma_{ENO \leq "E3"}(ASG)$
$ASG_2 = \sigma_{ENO > "E3"}(ASG)$
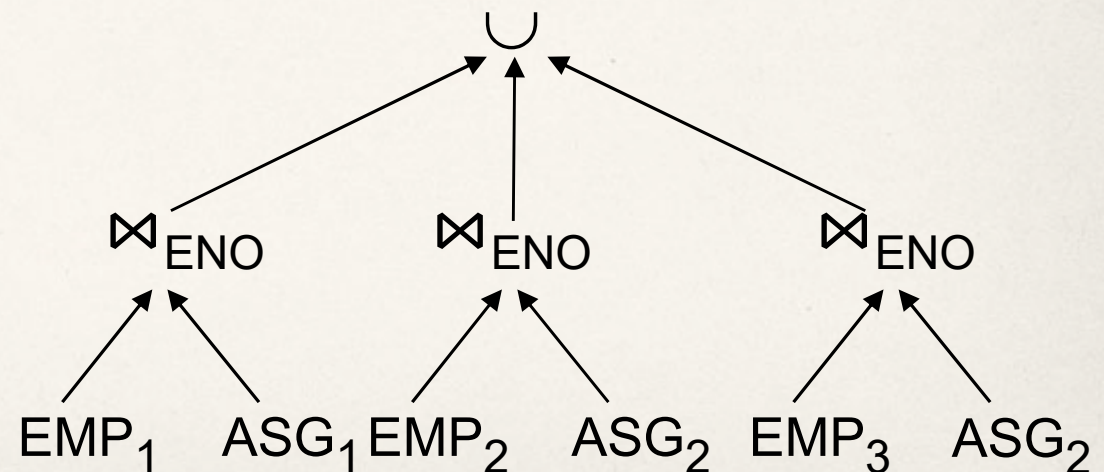
- Consider the query

```
SELECT   *
FROM     EMP,ASG
WHERE    EMP.ENO=ASG.ENO
```

- Distribute join over unions
- Apply the reduction rule

Not always useful

Reduction for VF

- Reduction of a projection over a relation fragmented with VF: ignore the fragment for which the set of fragmentation attributes intersected with the set of projection attributes is contained in the primary key

- Recall that the localization program consists in joins over key attributes

- Let R_1 be a fragment of R obtained as $R_1 = \Pi_{A'}(R)$ where $A' \subseteq attr(R)$:
  → Reduction of a projection $\Pi_{A''}$ over R_1 is possible when $A'' \cap A' \subseteq key(R)$

Ex.: $EMP_1 = \Pi_{ENO,ENAME}(EMP)$
$EMP_2 = \Pi_{ENO,TITLE}(EMP)$

```
SELECT   ENAME
FROM     EMP
```

$$\Pi_{ENAME}$$

$$\bowtie_{ENO}$$

EMP_1 EMP_2

➡

$$\Pi_{ENAME}$$

EMP_1
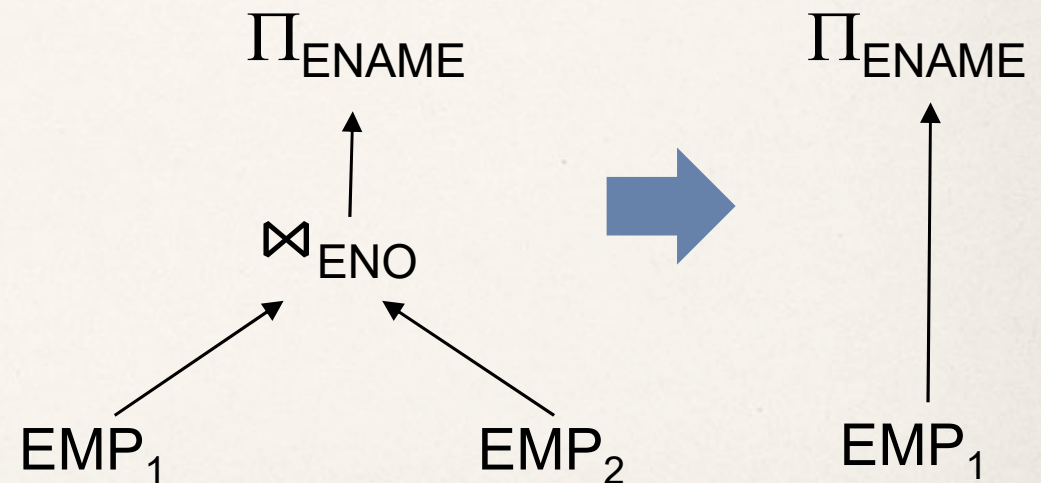
Reduction for DHF

- Similar to the case PHF
- DHF: 2 relations S (owner) and R (member) in association one-to-many
  - → S participates with cardinality N , R participates with cardinality 1
  - → Fragmentation propagate from S to R
  - → Localization program: union
  - → **Compatible fragments (i.e., fragments that agree on the values of join attributes) are placed at the same site**
- Reduction of a join over relations fragmented with DHF: only join compatible fragments
  - → Distribute joins over unions
  - → Apply the join reduction for horizontal fragmentation

Reduction for DHF – Example

- Example   [EMP is owner , ASG is member]

  EMP_1: $\sigma_{TITLE=\text{"Programmer"}}$ (EMP)
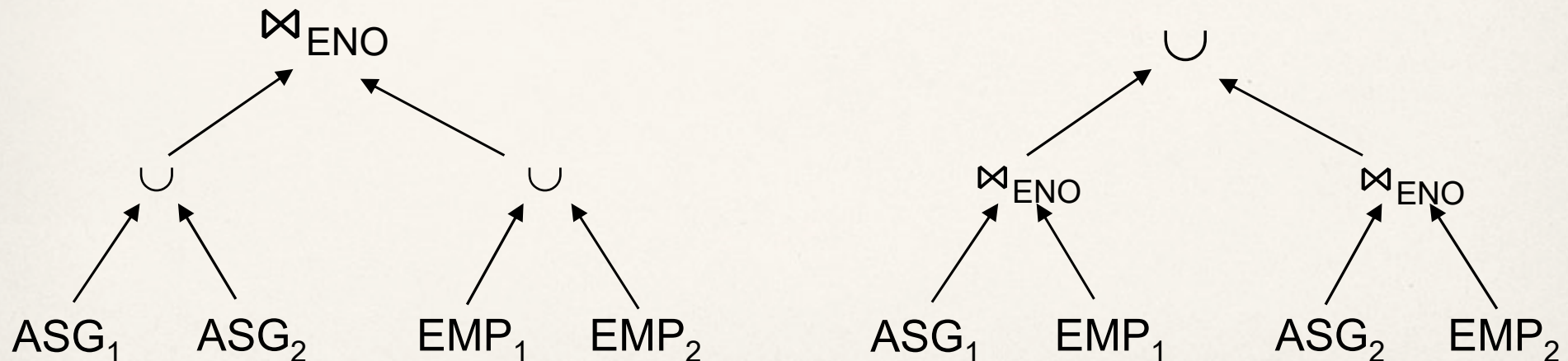 EMP_2: $\sigma_{TITLE \neq \text{"Programmer"}}$ (EMP)
  ASG_1: $ASG \ltimes_{ENO} EMP_1$
  ASG_2: $ASG \ltimes_{ENO} EMP_2$

- Query
  ```
  SELECT      *
  FROM        EMP, ASG
  WHERE       ASG.ENO = EMP.ENO
  ```

Reduction for DHF – Example

- Example [EMP is owner , ASG is member]

EMP_1: $\sigma_{TITLE="Programmer"}$ (EMP)

EMP_2: $\sigma_{TITLE \neq "Programmer"}$ (EMP)
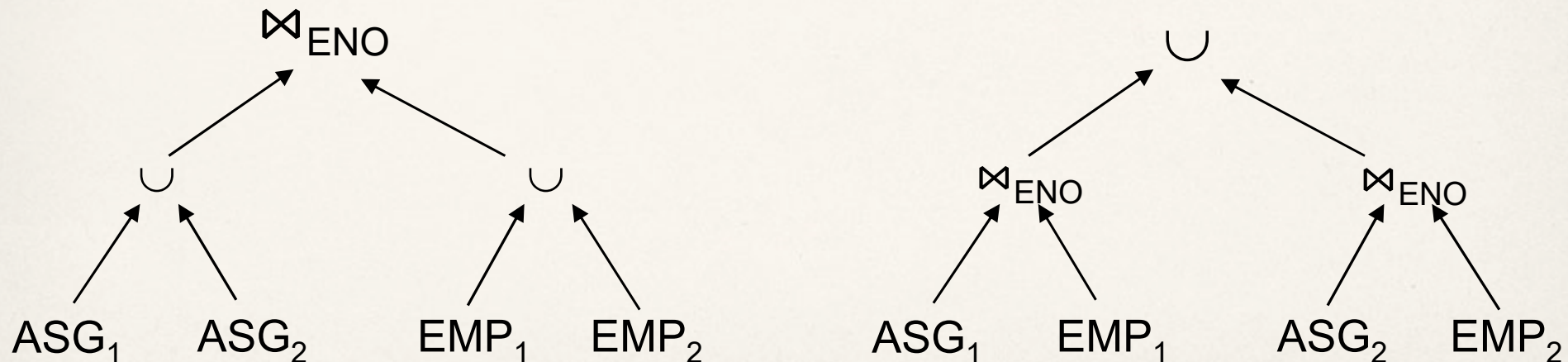
ASG_1: $ASG \ltimes_{ENO} EMP_1$

ASG_2: $ASG \ltimes_{ENO} EMP_2$

> **Always convenient**
> - the number of joins is always equal to the number of fragments
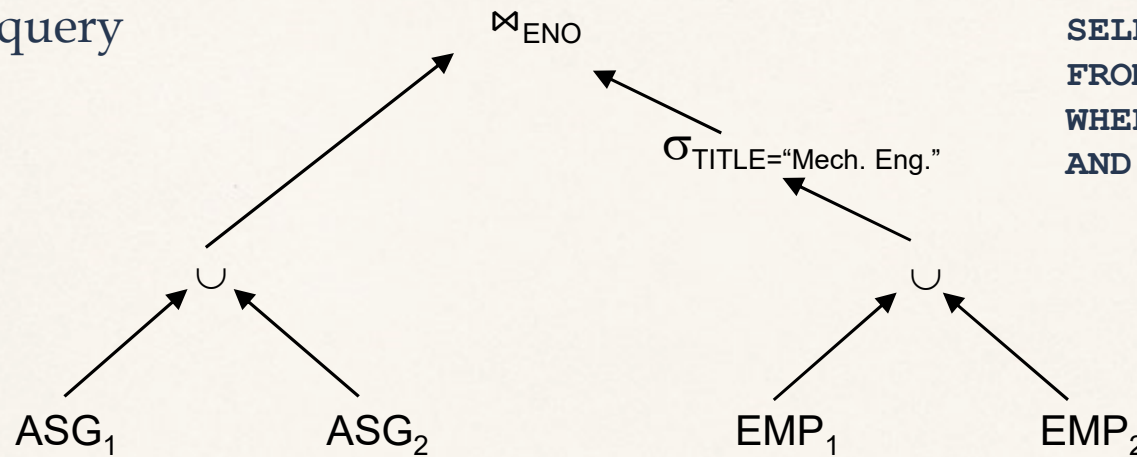> - all joins can be performed in parallel (are disjoint)

- Query

```
SELECT      *
FROM        EMP, ASG
WHERE       ASG.ENO = EMP.ENO
```

Complex reduction for PHF and DHF

1. Generic query

$$\bowtie_{ENO}$$

$$\sigma_{TITLE=\text{“Mech. Eng.”}}$$

$$\cup$$

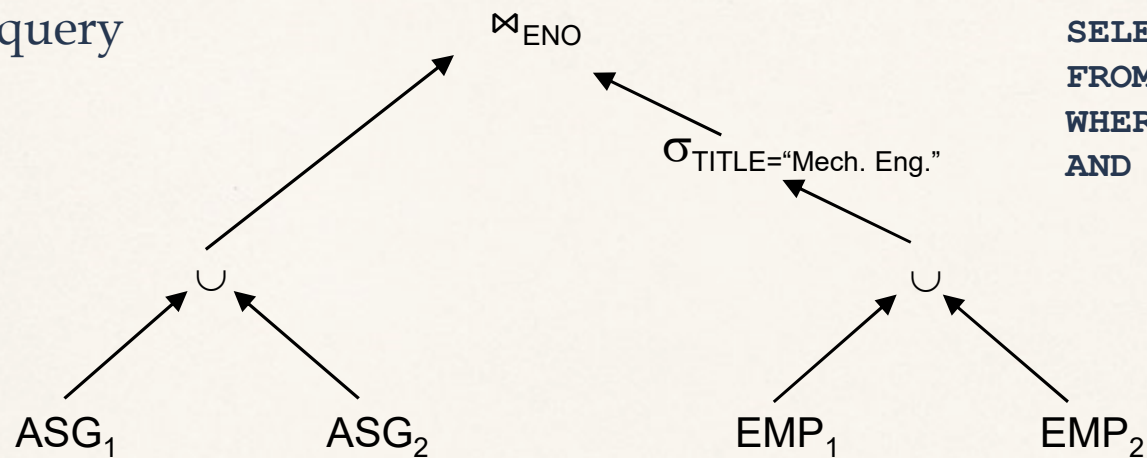$$\cup$$

ASG$_1$ ASG$_2$ EMP$_1$ EMP$_2$

```
SELECT *
FROM    EMP, ASG
WHERE   ASG.ENO = EMP.ENO
AND     EMP.TITLE = "Mech. Eng"
```

Complex reduction for PHF and DHF

1. Generic query

$$\bowtie_{ENO}$$

$$\sigma_{TITLE=\text{"Mech. Eng."}}$$

$$\cup$$

ASG$_1$ ASG$_2$

$$\cup$$

EMP$_1$ EMP$_2$

```
SELECT *
FROM    EMP, ASG
WHERE   ASG.ENO = EMP.ENO
AND     EMP.TITLE = "Mech. Eng"
```

2. Reduction of selection over a
   relation fragmented with HF

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Complex reduction for PHF and DHF

1. Generic query

$$\bowtie_{ENO}$$

$$\sigma_{TITLE=\text{"Mech. Eng."}}$$

$$\cup$$

ASG₁   ASG₂

$$\cup$$

EMP₁   EMP₂
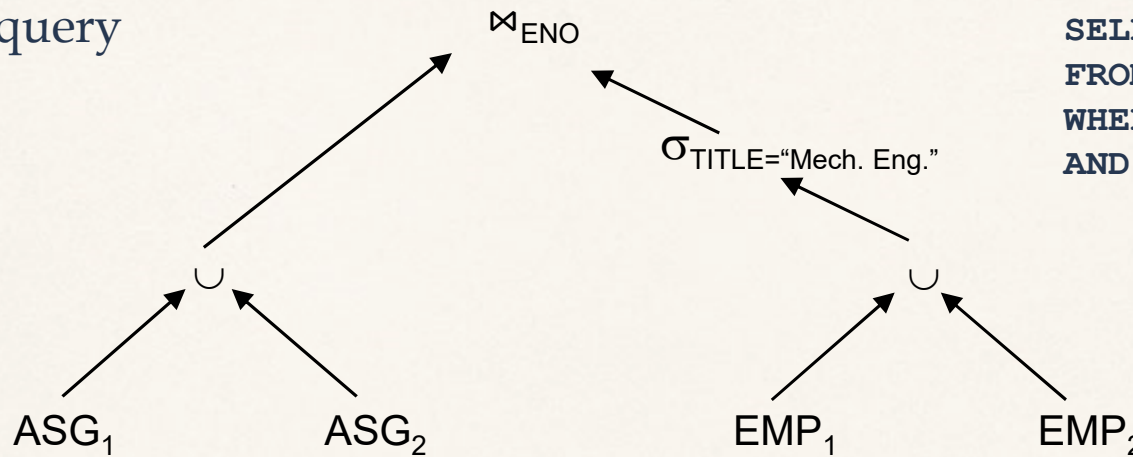
```
SELECT  *
FROM    EMP, ASG
WHERE   ASG.ENO = EMP.ENO
AND     EMP.TITLE = "Mech. Eng"
```

2. Reduction of selection over a
   relation fragmented with HF

$$\bowtie_{ENO}$$

$$\cup$$

$$\sigma_{TITLE=\text{"Mech. Eng."}}$$

ASG₁   ASG₂   EMP₂

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Complex reduction for PHF and DHF

1. Generic query

$\bowtie_{ENO}$

$\sigma_{TITLE="Mech.\ Eng."}$

$\cup$

ASG$_1$ ASG$_2$

$\cup$

EMP$_1$ EMP$_2$

```
SELECT  *
FROM    EMP, ASG
WHERE   ASG.ENO = EMP.ENO
AND     EMP.TITLE = "Mech. Eng"
```

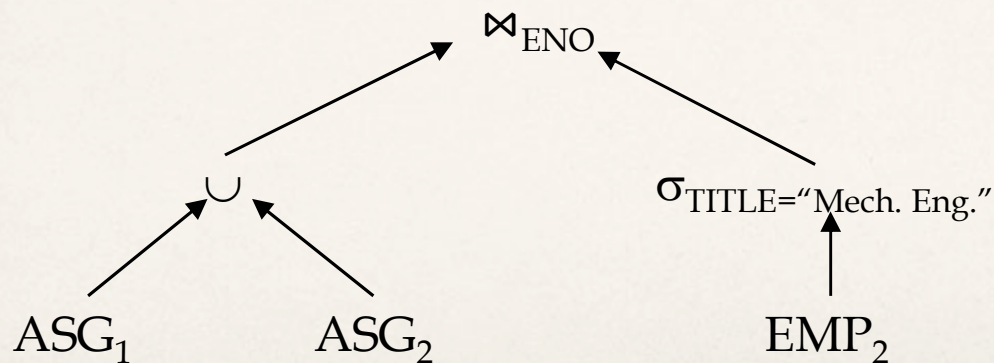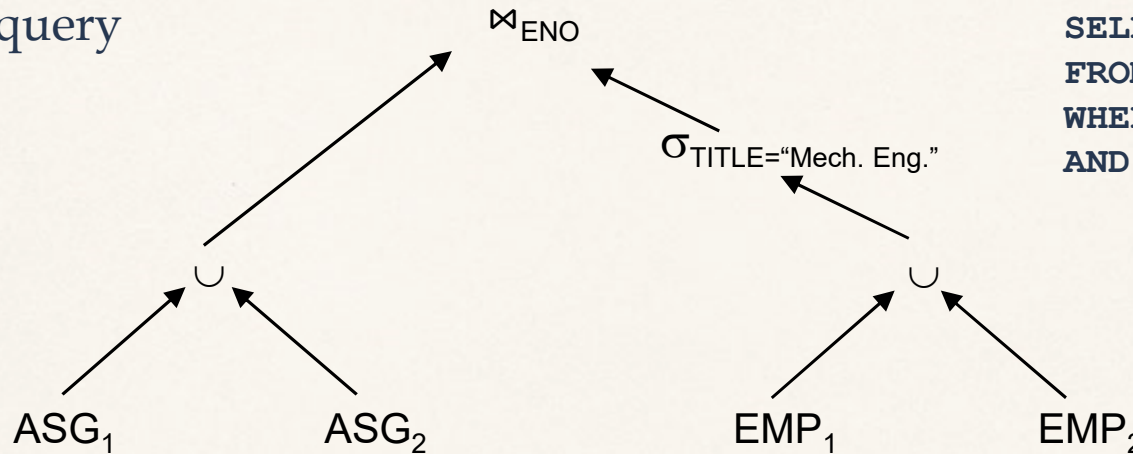**2. Reduction of selection over a relation fragmented with HF**

3. Reduction of join over a relation fragmented with DHF

$\bowtie_{ENO}$

$\cup$

ASG$_1$ ASG$_2$

$\sigma_{TITLE="Mech.\ Eng."}$

EMP$_2$

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Complex reduction for PHF and DHF

1. Generic query

$$\bowtie_{ENO}$$

$$\sigma_{TITLE=\text{"Mech. Eng."}}$$

$$\cup \qquad\qquad \cup$$

ASG$_1$ ASG$_2$ EMP$_1$ EMP$_2$

```
SELECT *
FROM   EMP, ASG
WHERE  ASG.ENO = EMP.ENO
AND    EMP.TITLE = "Mech. Eng"
```

2. Reduction of selection over a relation fragmented with HF
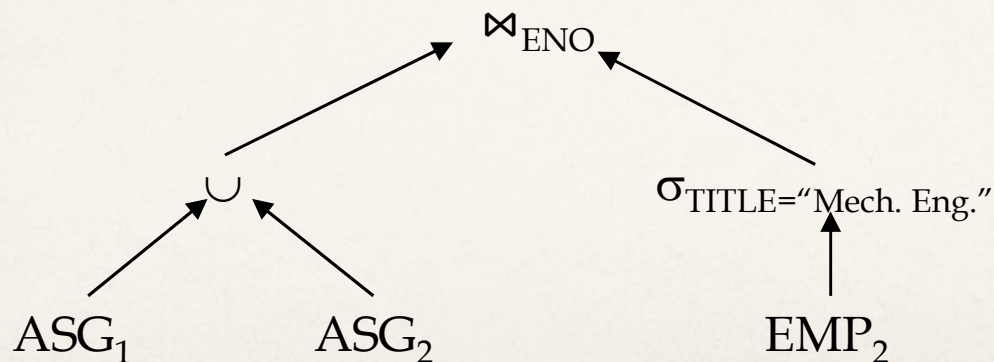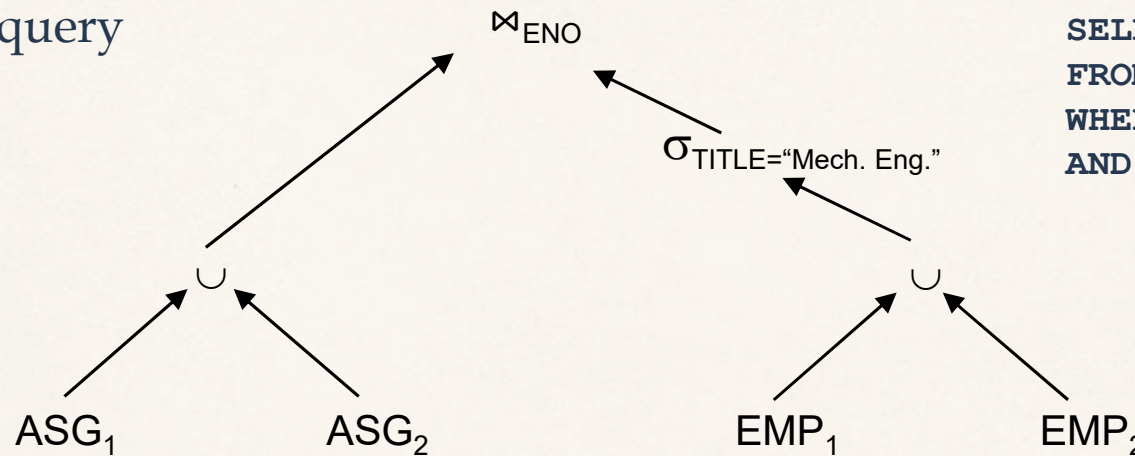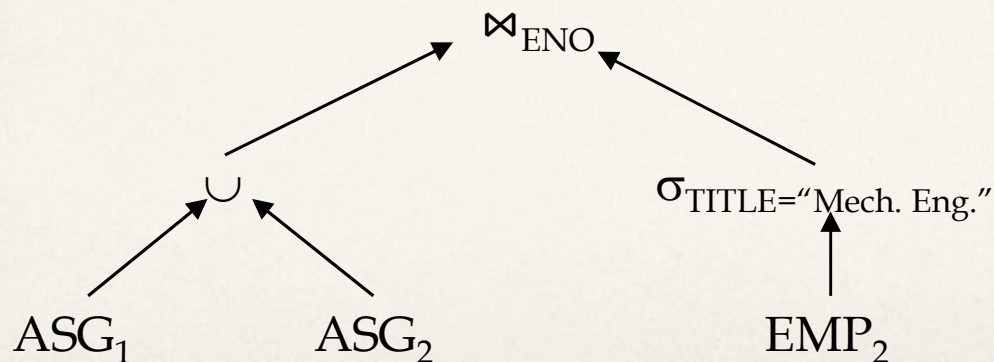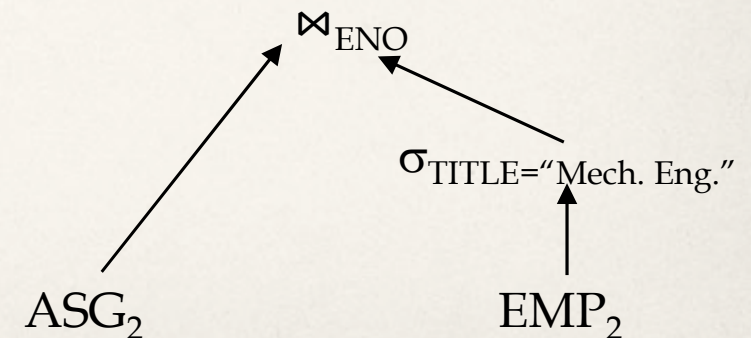
$$\bowtie_{ENO}$$

$$\cup \qquad \sigma_{TITLE=\text{"Mech. Eng."}}$$

ASG$_1$ ASG$_2$ EMP$_2$

3. Reduction of join over a relation fragmented with DHF

$$\bowtie_{ENO}$$

$$\sigma_{TITLE=\text{"Mech. Eng."}}$$

ASG$_2$ EMP$_2$

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Reduction for Hybrid Fragmentation

- Combine the rules already specified

  → Remove empty relations generated by contradicting predicates (inside selections or joins) on horizontal fragments

  → Remove useless relations generated by projections on vertical fragments

  → Distribute joins/selections/projections over unions in order to isolate and remove useless operands

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Reduction for Hybrid Fragmentation

Example

Consider the following hybrid fragmentation:

$$EMP_1 = \sigma_{ENO \leq "E4"} (\Pi_{ENO,ENAME} (EMP))$$

$$EMP_2 = \sigma_{ENO > "E4"} (\Pi_{ENO,ENAME} (EMP))$$

$$EMP_3 = \Pi_{ENO,TITLE} (EMP)$$

Thus, the localization program for EMP is:

$$EMP = (EMP_1 \cup EMP_2) \bowtie EMP_3$$

Consider also the query:

```
SELECT  ENAME
FROM    EMP
WHERE   ENO="E5"
```

Π_{ENAME}

$\sigma_{ENO="E5"}$

$\bowtie_{ENO}$

$\cup$

$EMP_1 \quad EMP_2 \quad EMP_3$

$\Rightarrow$

Π_{ENAME}

$\sigma_{ENO="E5"}$

EMP_2